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SOIL AND VEGETATION DEVELOPMENT IN AN ABANDONED SHEEP CORRAL ON DEGRADED SUBALPINE RANGELAND

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ABSTRACT.—Vegetation and soils inside and outside an abandoned sheep corral on degraded subalpine range of the Wasatch Plateau were studied to determine the influence of approximately 37 years' use of the corral on soil and plant development. Vegetal and surface cover were estimated. Herbage, litter, and soils were sampled inside and outside the corral and analyzed for C_{org}, N, P, and S. Soil pH, bulk density, and CO_3-C also were measured. Storage (mass/unit area) of C_{org}, N, P, and S was determined for each component. Yield and vegetal composition were significantly affected inside the corral boundary. Herbage yield was 2.2 times greater, litter mass 16 times greater, foliar cover of grasses 2 times greater, and forb cover 70% lower inside than outside the corral. Cover of meadow barley (*Hordeum brachyantherum*), a component of the predisturbance vegetation of the Wasatch Plateau, was nearly 12 times greater inside than outside the corral. These and other vegetal and cover differences reflect inside-outside differences in concentration, storage, and availability of soil C_{org}, N, P, and S. Concentrations of C_{org} and total and available N, P, and S were greater in the surface 5 cm of soil inside the corral. Available P inside the corral was much higher in all soil layers. Because of bulk density differences, storage was greater inside the corral only for C_{org} and N at 0–5 cm and for P at 5–15 cm. Lower soil pH inside the corral appears related to soil P distribution and CO_3-C storage. Results suggest a need to reexamine earlier conclusions that tall forbs are the climax dominants of the Wasatch summer range.

Key words: summer range; soil C_{org}, N, P, S, CO_3-C, pH, and bulk density; plant composition and cover; biomass yield; litter.

After 35 years of destructive grazing by cattle and sheep in the late 1800s, the subalpine range of the Wasatch Plateau east of Ephraim, Utah, was in extremely poor condition (Reynolds 1911, Sampson and Weyl 1918, Sampson 1919). Erosion and alteration of vegetal cover reached such severe proportions that most of the soil A horizon was lost to erosion, and mud-rock floods were a common occurrence in the canyons leading to valleys and settlements at the base of the Wasatch Front (Reynolds 1911, Croft 1967). In some places only subsoils remained when control of grazing was finally achieved with establishment of the Manti National Forest in 1903 (Reynolds 1911, Sampson and Weyl 1918, Ellison 1949). Although condition of the range improved steadily over the next several decades, most of the summer range was still unstable in 1950, and accelerated erosion was continuing but at greatly reduced rates (Ellison 1954, Meeuwig 1960).

Under moderate grazing secondary succession occurred from 1903 to about 1940 when it slowed perceptibly (Ellison 1954). Since then succession has been extremely slow (Johnson 1964, Intermountain Research Station, Ogden, Utah, unpublished data). Our observations suggest that soil and vegetal conditions have essentially stabilized since Ellison's last observations in the mid-1950s. We believe the slow rate of succession and range improvement in the Wasatch subalpine since then is directly attributable to extreme amounts of soil loss and relatively low fertility of soils that remained after the period of degradation. Based on examination of numerous soil profiles on the plateau and those of similar soils elsewhere, we believe at least 50%, and possibly as much as 80 or 90%, of the A horizon was lost from this summer range via accelerated erosion. Such a loss would certainly remove a large portion of the soil's organic matter and nutrient capital and significantly alter productive potential.

In recent years we have pursued this hypothesis with several studies. This paper reports the results of a fortuitous observational study designed to demonstrate the effect of organic matter and nutrient additions over time on development of soils and vegetation of the Wasatch subalpine range. During field

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studies in 1988, we happened upon an abandoned and dilapidated sheep corral that obviously had not been used in many years (Fig. 1). No remains of manure were present inside the corral; vegetation and litter development were advanced and perennial grasses were abundant (Fig 2A). The contrast with vegetation and litter outside of what remained of the corral fence was striking (Fig. 2B).

The corral offered an opportunity to document effects of use of the corral (1936–73) and inputs of organic matter and nutrients via sheep manure during its use to soil and vegetal development inside the corral boundary.

STUDY AREA

The Buck Ridge corral study site (39°15′N, 111°26′W) is located about 18 km east of Manti, Utah, on Cherry Flat adjacent to Buck Ridge Road and about 1.6 km east of Skyline Drive. This location is 5 km south of the Alpine Station and the well-known and studied Watersheds A and B of the Great Basin Experimental Range established by Dr. Arthur W. Sampson in 1912 (Sampson and Weyl 1918, Meeuwig 1960). Cherry Flat is typical of the crest of the Wasatch Plateau, which is about 3150 m elevation. The plateau is long, narrow, and oriented approximately north and south with riblike ridges extending east and west. The top of the plateau is gently rolling to nearly level. Average annual precipitation is about 840 mm; two-thirds of this falls as snow between November and April. Precipitation averages 173 mm during the summer months (June through September) but varies considerably. Mean annual temperature is about 0°C (Ellison 1954).

In the vicinity of the corral, Cherry Flat has a gentle 2% slope to the east; microtopography is smooth. Soil parent materials are of the Flagstaff Formation (Stanley and Collinson 1979) that crop out over about 7200 km^2 in central Utah (Schreiber 1988). Dominant lithology is freshwater lacustrine limestone and

Fig. 1. Remains of Buck Ridge corral as it appeared in 1989.

Fig. 2. Close-up view of vegetation and groundcover inside (A) and outside (B) Buck Ridge corral in 1989.

calcareous shales with minor interbeds of sandstone, oil shale, conglomerate, gypsum, and volcanic ash (Weber 1964, Schreiber 1988). Soils in this region of the plateau are mostly fine, mixed Argic Cryoborolls, but lithic, pachic, and vertic Cryoborolls also are present. They are shallow to moderately deep; the subsoils are silty clays or clay loams. Thickness of the A horizon averages about 4 cm; the B horizon averages approximately 52 cm thickness. Based on typical profile descriptions (H. K. Swenson, Soil Conservation Service, Boise, Idaho, personal communication), these relative horizon thicknesses suggest that much of the original A horizon was lost by wind and water erosion following the period of unrestricted grazing prior to 1903.

Vegetation of the Wasatch Plateau is chiefly herbaceous, but small patches of Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*) occupy steep northerly exposures of east-west ridges and dot the plateau landscape. Because there were no remnants of the original pristine vegetation (Ellison 1949, 1954), opinions differ regarding its exact character. Ellison (1954) describes the original plant community as mixed-upland herb dominated by tall forbs, while Sampson (1919) considered wheatgrasses to be the primary species of the herbaceous climax (i.e., what he referred to as summer range).

Based on file records and discussion with former permittees, we determined Buck Ridge corral was built and first used in 1936. It was last used about 1973 (Ed Shoppe, Manti-LaSal National Forest, Ephraim, Utah, personal communication). Hence, the corral was used annually by sheep for about 37 years. During this period undetermined and variable amounts of organic matter and nutrients were added annually via dung and urine, depending on the number and size of bands using the corral and frequency of use. For the past 10 years, the Buck Ridge allotment, comprising 4235 ac, has been grazed by sheep at the rate of 3.3 ac/AUM from 1 July to 30 September.

METHODS

As a basis for conducting this observational study, we first assured ourselves that areas inside and outside the corral boundary were initially alike in every respect and that site characteristics had no bearing on the precise location of the corral at the outset or on the findings. There were no differences in topography (or microtopography) and no evidence that other state factors (climate, biotic factor, parent material) differed within the small study site (about 0.75 ha) of the corral area. To assess the differential effect of nutrient additions inside and outside the corral, we sampled vegetation, litter, and soil in midsummer. Moisture conditions were dry at the time and little grazing had occurred inside or outside the corral. Present condition of the corral fence (Fig. 1) indicates that sheep have had near equal access to both sides of the corral boundary for many years, but there is no record of how long fence cross rails have been down.

Cover by species (foliar projection), litter, soil, and rock were estimated in 10 randomly located 0.5-m^2 plots inside and outside the corral (within 10 m of the corral boundary). Herbage and litter were harvested in the same plots, oven-dried (70°C), and weighed. Six randomly located soil pits were sampled inside and outside the corral. At each pit, soil cores (5.197 cm dia.) were collected from the 0–5-, 5–15-, and 15–30-cm layers. Plants and litter were ground to pass through a 0.425-mm sieve. Soils were air-dried, sieved to remove the >2-mm fraction, and then ground to pass through a 0.150-mm sieve.

Plant and soil samples were analyzed for total N by semi-micro-Kjeldahl (Bremner and Mulvaney 1982) and total S by dry combustion (Tiedemann and Anderson 1971) in a LECO high-frequency induction furnace (LECO Corp., St. Joseph, Michigan). Plant and soil samples were analyzed for total C by dry combustion (Nelson and Sommers 1982) in the LECO high-frequency induction furnace. Organic C (C_{org}) of soils was determined by correcting total C for carbonate-C as determined by a gasometric method (Dreimanis 1962). Total P was determined in plant material using the vanado-molybdo-phosphoric yellow color method after dry-ashing (Jackson 1958) and in soils using ascorbic acid color development (Olsen and Sommers 1982) following hydrofluoric acid digestion (Bowman 1988). Available nutrients in soils were determined as follows: P using ascorbic acid color development following 0.5 M sodium bicarbonate extraction (Olsen and Sommers 1982), N by steam distillation of 2 N KCl extracts (Keeney and Nelson 1982), and S with 1:1 water extracts, followed by ion chromatography (Dick and Tabatabai 1979).

Tests of significance for difference between inside and outside values for all variables studied were carried out with the *t* test. We recognize the desirability of replicating the inside-outside corral comparison. Unfortunately, that was not a design feature we could control; other abandoned corrals—even less than 37 years age—simply do not exist on this summer range.

RESULTS

Vegetation

Obvious visual differences in vegetation, litter, and soil surface conditions inside and outside the old corral (Figs. 2A, 2B) were confirmed in the data (Table 1). Herbage yield inside the corral was 2.2 times greater than outside. Although total herbage cover inside and outside the corral was the same (65%), grasses comprised a much greater percentage of foliar cover than did forbs inside than outside the corral. Three perennial grasses (*Agropyron trachycaulum*, *Hordeum brachyantherum*, and *Stipa lettermani*) dominated vegetal cover inside the corral (Table 2); outside the corral *A. trachycaulum* and *S. lettermani* were equally important, but *H. brachyantherum* was unimportant.

Forbs were represented by 7 species inside the corral and 11 species outside (Table 2). *Taraxacum officinale* and *Achillea millefolium* were the dominant forbs inside and outside the corral, but their cover outside was much greater than inside. No other forb species constituted more than 4% of the herbage composition.

Soil surface protection by litter differed markedly inside and outside the corral. Mass of litter inside the corral was 16 times greater

TABLE 1. Influence of long-term corral effects on vegetation, litter, and soil surface characteristics at Buck Ridge.

Component and attribute	Inside	Outside	Difference sign. at $P <$
Herbage yield (g m^{-2})	139 ± 21[a]	64 ± 9	.005
Litter mass (g m^{-2})	312 ± 78	19 ± 2	.005
Foliar cover (%)			
Grasses	55 ± 5	28 ± 5	.001
Forbs	11 ± 3	37 ± 8	.05
Total	66 ± 3	65 ± 7	NS
Basal cover (%)			
Litter	71 ± 4	18 ± 4	.001
Bare ground + rock	3 ± 2	25 ± 4	.005

[a]Mean ± standard error; n = 10.

than outside, while cover of litter was 4 times greater (Table 1). This is consistent with the 12-fold difference in bare ground between inside and outside locations. Only 2% of the soil surface was bare inside the corral.

NUTRIENTS

Concentrations of all nutrients studied were influenced by dung and urine accumulation inside the corral (Table 3). Nitrogen concentration was higher in the herbage, litter, and 0–5-cm soil layer, but lower in the 15–30-cm soil layer inside than outside the corral. Concentration of C_{org} was parallel to that of N for the litter and soil layers, while P concentration was higher inside than outside only for litter and the 0–5-cm soil layer (Table 3). Concentration of S was higher inside than outside only for the upper soil layer.

Storage (mass/unit area) of all four nutrients was significantly greater inside than outside the corral for herbage and litter components (Table 4). Amounts of C_{org} were greater inside the corral in the surface soil, but lower in the 15–30-cm soil layer. Storage of N was greater inside the corral in the 0–5-cm soil layer, while storage of P was greater inside the corral in the 5–15-cm soil layer.

Availability of P was much higher inside than outside the corral in all soil layers (Table 5). Availability of N and S was significantly higher ($P < .10$) inside the corral only in the 0–5-cm soil layer.

TABLE 2. Percentage of species composition (by foliar cover) of vegetation inside and outside Buck Ridge corral.

	Percentage	
	Inside	Outside
GRASSES		
Agropyron trachycaulum	8.2	10.3
Alopecurus pratensis		1.6
Bromus carinatus	4.0	
Hordeum brachyantherum	35.6	3.0
Poa pratensis		0.7
Stipa columbiana	0.4	
Stipa lettermani	30.4	26.5
Total grasses	78.6	42.1
FORBS		
Achillea millefolium	8.8	18.0
Androsace septentrionalis	0.3	0.3
Artemisia ludoviciana v. *incompta*		2.7
Aster foliaceus v. *canbyi*		2.4
Cymopteris lemmonii		0.2
Descurania richardsonii	0.9	0.1
Erigeron ursinus		2.6
Gilia aggregata		0.2
Lesquerella utahensis		2.1
Polygonum glandulosa	0.2	
Ranunculus inamoenus	0.3	
Rumex mexicanus	3.5	
Taraxacum officinale	7.4	29.2
Viola nuttallii v. *nuttallii*		0.1
Total forbs	21.4	57.9

DISCUSSION AND CONCLUSIONS

Development of vegetation and stabilization of the soil surface at Buck Ridge corral were indeed striking considering the slow pace of secondary succession of the Wasatch summer range from 1903 to 1940 (Ellison 1954, Meeuwig 1960) and the apparent lack of trend since 1940. Values for herbage production, litter mass, and cover data portray control of the soil surface inside the corral and are in marked contrast to conditions outside the corral and the surrounding summer range, which is still relatively unstable and subject to accelerated erosion. We believe the vegetation trend observed inside the corral has occurred within a relatively short time—no more than 20 years, assuming vegetal development did not commence until after abandonment of the corral. This is not to say that ephemerals did not occupy the corral annually between periods of use, only to be eliminated during use.

The large changes in vegetation and soil surface conditions are consistent with changes in nutrient status of the soil-plant-litter system

TABLE 3. Concentration of C_{org}, N, P, and S in components of the soil-plant-litter system inside and outside Buck Ridge corral.

Nutrient	Component		Inside	Outside	Difference sign. at $P <$
			g kg^{-1}		
C_{org}	Herbage		447.4 ± 7.1[a]	433.0 ± 4.2	NS
	Litter		420.0 ± 8.3	448.9 ± 7.2	.025
	Soil,	0–5 cm	134.2 ± 17.6	45.6 ± 2.2	.001
		5–15 cm	34.8 ± 2.7	39.5 ± 1.4	NS
		15–30 cm	21.8 ± 2.5	36.4 ± 2.0	.005
N	Herbage		21.75 ± 0.75	15.50 ± 0.82	.001
	Litter		19.48 ± 0.83	11.77 ± 0.77	.001
	Soil,	0–5 cm	14.05 ± 1.95	3.39 ± 0.21	.001
		5–15 cm	2.99 ± 0.23	3.05 ± 0.10	NS
		15–30 cm	1.89 ± 0.17	2.73 ± 0.17	.005
P	Herbage		2.23 ± 0.10	2.22 ± 0.21	NS
	Litter		1.99 ± 0.12	1.47 ± 0.08	.001
	Soil,	0–5 cm	2.36 ± 0.22	1.61 ± 0.06	.01
		5–15 cm	1.70 ± 0.13	1.44 ± 0.08	NS
		15–30 cm	1.36 ± 0.13	1.39 ± 0.09	NS
S	Herbage		1.29 ± 0.04	1.22 ± 0.04	NS
	Litter		1.10 ± 0.07	0.96 ± 0.10	.05
	Soil,	0–5 cm	1.42 ± 0.18	0.88 ± 0.08	.025
		5–15 cm	0.69 ± 0.22	0.74 ± 0.11	NS
		15–30 cm	0.68 ± 0.11	0.71 ± 0.05	NS

[a]Mean ± standard error; $n = 6$.

over the life of the corral and subsequent to its abandonment (Crocker and Major 1955, Olson 1958, Blackmore et al. 1990). Unfortunately, much of the corral history (actual herd use, inputs of dung and urine, and character of vegetation that occupied the corral between periods of use by sheep) was not documented. However, changes in concentration and accumulation of nutrients inside the corral seem reasonable, based on what might be expected from traditional use of a subalpine corral by sheep for 37 years, experience from other grazed systems (Blackmore et al. 1990, Scholes 1990), and an understanding of the chemistry of the elements studied here. We can be confident that concentrations of soil C_{org} and N inside the corral have declined since abandonment and change in the biotic factor (Jenny 1941). However, whether a new steady state has been reached yet is conjectural (Jenny 1941, Tiedemann and Klemmedson 1986), even though observed concentrations of soil C_{org} and N are within the range for comparable undisturbed soils (Retzer 1956, Youngberg and Dyrness 1964).

Because C, N, P, and S are ubiquitous in soil organic matter and its precursors (Stevenson 1986), close association among these elements should be expected in components of the Buck Ridge soil-plant-litter system, especially between C_{org} and N because soil N is almost entirely organic (i.e., about 98%). On the other hand, because of certain dissimilarities in the chemistry of these four nutrients and differences among them in physiological separation into dung and urine pathways (C and P entirely via dung, N and S predominately via urine; Floate 1970, O'Connor 1981, Barrow 1987, Sagger, MacKay et al. 1990), certain differences in nutrient accumulation patterns can be expected.

Close association of C_{org} and N was apparent even in the 15–30-cm soil layer where concentration of C_{org} and N and amount of C_{org} were lower inside than outside the corral. Such an unexpected difference at this depth lacks explanation, certainly none related to corral effects. It is not consistent with the large differences in C_{org} and N in the litter and 0–5-cm soil layer where effects of the corral would be most expected. Parent material seems the most likely cause of this difference, but samples from the study site were uniform in CO_3-C and varied randomly in N, P, and S. However, limestone and shales are noted for spatial variation, even within very short

TABLE 4. Storage of C_{org}, N, P, and S in components of the soil-plant-litter system inside and outside Buck Ridge corral.

Nutrient	Component	Inside	Outside	Difference sign. at $P <$
		- - - - kg m^{-2} - - - -		
C_{org}	Herbage	0.064 ± 0.007[a]	0.028 ± 0.004	.001
	Litter	0.129 ± 0.032	0.009 ± 0.001	.005
	Soil, 0–5 cm	3.46 ± 0.17	1.84 ± 0.13	.001
	5–15 cm	4.44 ± 0.61	3.94 ± 0.25	NS
	15–30 cm	4.30 ± 0.62	6.44 ± 0.63	.05
	Soil total[b]	12.19 ± 1.29	12.22 ± 0.80	NS
	Total system	12.34 ± 1.27	12.25 ± 0.80	NS
		- - - - g m^{-2} - - - -		
N	Herbage	3.17 ± 0.27	1.03 ± 0.16	.001
	Litter	6.23 ± 1.68	0.23 ± 0.04	.001
	Soil, 0–5 cm	348 ± 16	138 ± 10	.001
	5–15 cm	379 ± 50	304 ± 17	NS
	15–30 cm	370 ± 46	485 ± 50	NS
	Soil total	1079 ± 96	927 ± 62	NS
	Total system	1115 ± 105	928 ± 152	NS
P	Herbage	0.33 ± 0.04	0.15 ± 0.03	.001
	Litter	0.66 ± 0.18	0.03 ± <0.01	.005
	Soil, 0–5 cm	63 ± 4	64 ± 3	NS
	5–15 cm	216 ± 30	145 ± 14	.10
	15–30 cm	231 ± 43	250 ± 32	NS
	Soil total	551 ± 70	460 ± 44	NS
	Total system	552 ± 70	461 ± 44	NS
S	Herbage	0.19 ± 0.02	0.08 ± 0.01	.001
	Litter	0.37 ± 0.11	0.02 ± <0.01	.01
	Soil, 0–5 cm	37 ± 2	35 ± 3	NS
	5–15 cm	90 ± 16	77 ± 14	NS
	15–30 cm	134 ± 25	128 ± 18	NS
	Soil total	261 ± 42	241 ± 33	NS
	Total system	262 ± 42	241 ± 33	NS

[a]Mean ± standard error; n = 10 for herbage and litter, 6 for soil components.
[b]0–30 cm

distances (C. F. Lohrengel, Department of Geology, Snow College, Ephraim, Utah, personal communication). Of 23 rock samples from the near vicinity (4-km radius) classified by Schreiber (1988), P concentration ranged 31-fold, with a C.V. of 1.46. The sample highest in P content, an organic-rich shale, burned under a match flame.

Phosphorus is relatively immobile but should accumulate in soils over time where P inputs exceed removal in grazed herbage (Sagger, Hedley et al. 1990). This would characterize the situation in Buck Ridge corral with the large inputs of animal excreta from 1936 to 1973. Moreover, decomposition of this material should facilitate P mobility, especially after pulverization by hoof action (Bromfield and Jones 1970). Although urine and dung hydrolyze rapidly causing NH_4 to accumulate and pH to rise, nitrification quickly takes over and, in the case of urine, within days pH will drop below control levels (Doak 1952, During et al. 1973, Haynes and Williams 1992). Indeed the initial impact of decomposition of most plant materials is an increase in bulk pH (Williams and Gray 1974). However, products of organic decay are predominantly acid; hence, acidification eventually dominates. Those horizons or soil layers that contain the products of primary decomposition, in this case the litter and 0–5-cm layer (Table 6), will show the greatest acidity (Swift et al. 1979) and a tendency for enhanced solubility and mobility of P. Significantly lower carbonate-C of soil inside than outside the corral (Table 6) manifests increased soil acidity inside the corral. James Clayton (personal communication, Intermountain Research Station, Boise, Idaho) suggests the CO_3-C difference inside and outside the corral is reasonable, based on estimated H^+ supplied by nitrification of urea and organic matter decomposition over a period of 37 years.

TABLE 5. Concentration of available soil N, P, and S inside and outside Buck Ridge corral.

	N			P			S		
Soil Layer	Inside	Outside	Diff. sign. $P <$	Inside	Outside	Diff. sign. $P <$	Inside	Outside	Diff. sign. $P <$
	----- mg kg^{-1} -----			----- mg kg^{-1} ----			----- mg kg^{-1} ----		
0–5 cm	105 ± 26[a]	52 ± 11	.10	158 ± 19	57 ± 6	.001	50 ± 13	22 ± 3	.10
5–15 cm	29 ± 7	20 ± 3	NS	142 ± 16	22 ± 4	.05	24 ± 2	22 ± 1	NS
15–30 cm	13 ± 3	13 ± 2	NS	70 ± 11	10 ± 3	.001	15 ± <1	14 ± 1	NS

[a]Mean ± standard error; $n = 6$.

The P distribution pattern described here is similar to that found by Sagger, MacKay et al. (1990), who closely predicted observed P accumulation in soil of sheep pastures. In areas where sheep camped, 85–90% of P accumulated in the upper 15 cm of soil was accounted for by animal waste. Williams and Haynes (1992) noted significant increases of P in the top 20 cm of soil in pastures grazed by sheep for 38 years and treated with superphosphate.

Nitrogen and S losses from the corral soil-plant system could have been large. Nitrogen may be lost by volatilization of NH_3, leaching and surface runoff of NO_3, or denitrification under appropriate conditions (Ball et al. 1979, Floate 1981, O'Connor 1981), while SO_4 may be lost by surface runoff and leaching, depending on SO_4 retention capacity of soils (Sagger, Hedley et al. 1990). Williams and Haynes (1992) assumed most of the S loss they observed (48–73%) was due to leaching. Thus, whether Buck Ridge corral was devoid of vegetation during much of the year and hence subject to leaching and runoff, or whether its use was intermittent so as to permit vigorous growth of ephemerals and uptake of available nutrients, we would not expect mineralized N and S to accumulate in the soil profile.

Similarity in P and S accumulation in the 0–5-cm soil layer, in view of higher concentrations of these nutrients, is attributed to lower bulk density of the upper soil layer inside the corral (Table 6). By contrast, bulk density of the 5–15-cm layer was significantly greater inside than outside the corral. These opposite trends in adjacent soil layers appear to be due to compaction of the entire upper 15 cm during 37 years of use of the corral by sheep, followed by amelioration of this effect in the absence of trampling after the corral was abandoned, especially in the top 5 cm where organic matter was concentrated (Tables 3, 4). Heavy clay subsoils of this site should compact readily. Sommerfeldt and Chang (1985) found that long-term manure treatments reduced bulk density of the upper 15 cm of a cultivated soil by as much as 39%.

Increased availability of nutrients in the upper 5 cm of soil of the corral soil is associated with higher concentration of nutrients and the large pool of organic matter in that layer. Carbon/element ratios of all soil-plant components (Table 7) indicate that conditions generally more favorable for net mineralization of N and P (Stevenson 1986) prevailed inside than outside the corral at the time of sampling. Greater availability of P in all soil layers inside the corral also can be associated with pH in a range that one might expect maximum availability of the labile inorganic P fraction (Stevenson 1986). Coupled with this is low mobility of P, in contrast to N and S, which allows P to be retained in place.

Since abandonment of the corral, organic matter would have continued to accumulate, but from a new source, i.e., autotrophic production of vegetation that presumably developed soon after corral abandonment. Significant import of new nutrients since abandonment is unlikely. Almost all nutrients in post-abandonment crops of herbage would have been recycled from the soil. Presumably, the level of herbage production inside the corral has exceeded that outside almost since abandonment owing to higher fertility status of soils inside the corral. The present condition of the corral fence (Fig. 1) would indicate that it has not been a barrier to sheep for many years. Hence, differential grazing probably has played a minor role in vegetal differences inside and outside the corral boundary. Although we have emphasized the role of nutrients in the observed changes, we cannot dismiss the possibility that improvement in moisture-holding capacity of surface soils

TABLE 6. Effects of inside and outside positions of Buck Ridge corral on bulk density, pH, and carbonate-C of soil layers.

Soil property	Soil layer (cm)	Inside	Outside	Difference sign. at $P <$
Bulk density (mg m^{-3})	0–5	0.59 ± 0.08[a]	0.84 ± 0.06	.05
	5–15	1.26 ± 0.04	1.10 ± 0.02	.005
	15–30	1.39 ± 0.06	1.26 ± 0.10	NS
pH	0–5	6.58 ± 0.11	7.23 ± 0.13	.005
	5–15	7.15 ± 0.06	7.28 ± 0.09	NS
	15–30	7.17 ± 0.06	7.37 ± 0.09	.10
Carbonate-C concentration (g kg^{-1})	0–5	5.20 ± 0.82	8.92 ± 1.87	.10
	5–15	5.35 ± 1.24	9.23 ± 2.10	NS
	15–30	4.13 ± 0.94	10.63 ± 2.19	.05
amount (kg m^{-2})	0–5	0.15 ± 0.04	0.38 ± 0.10	.10
	5–15	0.65 ± 0.13	0.74 ± 0.17	NS
	15–30	0.77 ± 0.15	1.80 ± 0.36	.025
	Soil	1.57 ± 0.25	3.05 ± 0.54	.05

[a]Mean ± standard error, n = 6.

TABLE 7. Carbon-element ratios of soil-plant-litter components for inside and outside positons of Buck Ridge corral.

Ratio	Component		Inside	Outside	Difference sign. at $P <$
C/N	Herbage		19.6 ± 0.8[a]	30.7 ± 2.6	.05
	Litter		22.4 ± 1.0	37.2 ± 3.6	.05
	Soil,	0–5 cm	10.0 ± 0.2	13.3 ± 0.6	.001
		5–15 cm	11.7 ± 0.5	13.0 ± 0.5	NS
		15–30 cm	11.5 ± 0.6	13.4 ± 0.6	.05
C/P	Herbage		210 ± 15	241 ± 44	NS
	Litter		241 ± 23	308 ± 15	.05
	Soil,	0–5 cm	56 ± 5	29 ± 2	.001
		5–15 cm	21 ± 1	28 ± 2	NS
		15–30 cm	16 ± 1	27 ± 2	.025
C/S	Herbage		346 ± 16	368 ± 17	NS
	Litter		406 ± 43	439 ± 55	NS
	Soil,	0–5 cm	95 ± 5	54 ± 5	.001
		5–15 cm	53 ± 5	61 ± 11	NS
		15–30 cm	34 ± 3	53 ± 5	.01

[a]Mean ± standard error; n = 10 for herbage and litter, 6 for soil components.

inside the corral also may have influenced the successional trend following abandonment.

Comparison of basal cover data for Buck Ridge corral (inside and outside) with that portraying conditions in 1946 for six "relic natural areas" and four stands on Elk Knoll (Elk Knoll Research Natural Area), as described by Ellison (1954), is revealing (Table 8). Similarity between cover of litter, bare ground, and rock at Elk Knoll (3.2 km west-northwest of Buck Ridge corral) in 1946 and in 1989 and what we found outside Buck Ridge corral supports observations that successional trend has been virtually static in the last 40-odd years. Although Elk Knoll had been previously grazed, it has been protected from grazing, except for wildlife, from 1903 (Ellison 1954) to the present. According to Ellison, the natural areas, which he claimed had never been grazed by domestic livestock or had been grazed only lightly for many years, provided a partial description of pristine vegetation in the Wasatch subalpine at that time.

Vegetal cover data (Table 1) demonstrate a marked trend toward perennial grasses inside the corral. We interpret this as an upward

TABLE 8. Comparison of cover data for Buck Ridge corral with Ellison's data for "relic natural areas" and sites at Elk Knoll.

Location	Litter cover	Bare ground + rock
	--------- % ---------	
Buck Ridge corral		
Inside corral	71	3
Outside	18	25
"Relic natural areas"[a]	11–20	11–50
Elk Knoll		
1946[a]	26–31	29–37
1989[b]	27–49	17–39

[a]See Ellison (1954).
[b]Klemmedson and Tiedemann, unpublished data

trend in succession; vegetation changes are accompanied by greater herbage production, increased litter mass and cover, and stability of the soil surface. These characteristics have been commonly associated with improvement toward high range (ecological) condition (Laurenroth and Laycock 1989).

Interestingly, herbage composition inside the corral is in marked contrast to that described by Ellison (1954) for his six relic natural areas. He said that "one of the most striking things about the natural areas is the abundance of perennial forbs"; they constituted 70–88% of the vegetation in relic natural areas in 1946. The trend toward perennial grasses (79% of total foliar cover) we have observed inside the corral is quite the opposite of Ellison's composition data and corresponds more to vegetation development of the summer range described by Sampson (1919). The increase in *Hordeum brachyantherum* also suggests an upward trend. Both Ellison (1954) and Sampson (1919) noted the presence of *H. nodosum*, a synonym misapplied to *H. brachyantherum* (Hitchcock 1950, Holmgren and Reveal 1966), on the summer range. But only Sampson (1919) discussed successional status; he described *H. nodosum* as a shallow-rooted species that occupied space between bunched wheatgrasses, the primary species of the subclimax type. He did not list this plant with types of lower developmental stage.

Normally where ecosystem degradation has been as severe as experienced here, with almost complete loss of the A horizon, we would expect successional processes in soil and vegetation to occur simultaneously (Sampson 1919, Crocker and Major 1955, Olson 1958). But, in this case where livestockmen controlled the input of manure and associated effects for 37 years, ecosystem development was essentially one-sided; soil development advanced rapidly for 37 years before sheep use of the corral ceased and development of vegetation was allowed to proceed. The fact that development in vegetation, litter, and soil surface conditions has advanced so far in just 20 years, far outpacing comparable development outside the corral, even in Ellison's "relic natural areas," leads us to conclude that soil fertility has been a key factor controlling succession and improvement of the Wasatch summer range.

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